Environmental Engineering and Management Journal March 2018, Vol.17, No. 3, 697-704
http://www.eemj.icpm.tuiasi.ro/; http://www.eemj.eu

"Gheorghe Asachi" Technical University of Iasi, Romania

ESTIMATING CURRENT STATE OF SOIL EROSION INDUCED BY SKID TRAILS GEOMETRY IN MOUNTAINOUS CONDITIONS

Cristian Ionuţ Duţă, Stelian Alexandru Borz*, Adrian Sălăjan

Transilvania University of Braşov, Faculty of Silviculture and Forest Engineering, Department of Forest Engineering, Forest Management Planning and Terrestrial Measurements, Şirul Beethoven, no. 1, 500123, Braşov, Romania

Abstract

Timber harvesting activity represents one of the major sources of the forest terrain erosion. Several studies have been performed in order to quantify the rate of soils erosion by considering the practices used in forestry, and some of them concluded that the associated erosion can be regarded as the price of having roads. The current study focused on the used practices in developing skidding trails and the associated erosion phenomena. There was found that some of the used practices (the longitudinal design slope of the skid trails) present major influences on the average eroded areas in cross-section. Correlations were established between the two mentioned factors, and there has been concluded that the design slopes greater than 20-25% led to the increment of the associated (affected) cross-section areas. Also, due to their main properties, different soil types can lead to increased scoured areas. There was found that the soils presenting parent rock layers closer to the surface are less susceptible to the process advancement by comparison with the more profound soils.

Key words: erosion, geometry, skid trail, timber skidding

Received: October, 2012; Revised final: January, 2013; Accepted: January, 2013; Published in final edited form: March 2018

1. Introduction

Timber harvesting is a complex product-delivery system (Oprea, 2008) which is implemented to provide wood to the industries and to the end users. Together with the downstream industries, it contributes to the welfare of rural areas (Gligoraş and Borz, 2015) and to the national gross domestic products (GDP). For instance, in the European Union, 58% of the harvested lignocellulosic biomass is processed by the forestry-related industries accounting for 7% of the EU's processing industry GDP and employing 3.5 million people (European Commission, 2014). To this end, forest engineering deals with the understanding of fundamental principia that characterize the behavior of timber harvesting systems, aiming to develop methods, concepts and tools which support the design, development, analysis and implementation of timber harvesting systems which should be bio-physically effective, economically efficient, compatible with the work force, environmentally-sound and institutionally accepted (Heinimann, 2007).

While there are many technical options that can be chosen for a given timber harvesting area, their choice is often affected by the equipment availability and other technical constraints. In Romania, for instance, ground-based, partly mechanized harvesting systems predominate in timber harvesting operations (Moskalik et al., 2017) as a consequence of a series of technical constraints mainly related to a poorly developed transportation infrastructure (Rauch et al., 2015). In addition, the Romanian forests are predominantly distributed in alpine, sloped terrains where cable yarding is one of the recommended options in harvesting operations (Oprea, 2008). Nevertheless, cable yarding requires a proper development of transportation infrastructure while the

* Author to whom all correspondence should be addressed: e-mail: stelian.borz@unitbv.ro, Phone: 0040 742 042455, Fax: 0040 268 47 57 05

modern, highly-productive equipment is still technically constrained by the quasi-absence of forest roads (Borz et al., 2014a). This results in a predominance in use of ground-based skidding both in alpine (Borz et al., 2013; Borz et al., 2014b) and hilly regions (Borz et al., 2015) and of animal traction (Ciobanu and Borz, 2013), coupled both with motor-manual tree felling and processing (Borz et al., 2014c; Ciobanu and Borz, 2013; Ignea et al., 2017). Only to a minor extent, equipment such as cable yarders (Munteanu et al., 2017) harvesters and forwarders (Apăfăian et al., 2017) were documented and are used in Romania.

There are many ways to evaluate the environmental effectiveness of a given product system. A detailed and commonly used approach is that of carrying on Life Cycle Analyses (LCA) to account for the environmental performance (Heinimann, 2012). Yet, its use hardly accounts for some of the environmental features such as soil impact while the wood extraction using ground-based equipment affects the soil in many ways.

For instance, erosion is a process which may be employed both, by the natural forces as well as by the human activity. While it depends on topography (Christopher and Visser, 2007), typically, the extent of the erosion processes in timber harvesting operations is the effect of the infrastructure used in transportation operations (Anderson, 1954; Dyrness, 1967). In timber transportation operations, it is estimated that the forest roads are accountable for up to 85% of the erosion processes (Furbish, 1981). Also, the skid trails have been identified as being one of the major erosion sources in forested terrains (Christopher and Visser, 2007; Hartanto et al., 2003; Nolan et al., 1995). More recently (Rice, 1999), it has been concluded that the forestry practices have a critical influence on the erosion processes associated with timber harvesting. One way to improve the forestry practices in steep terrains, therefore to control the erosion, is to switch the timber harvesting technology to cable yarding (Oprea, 2008), as such equipment impacts only the top layers of the soil (Laffan et al., 2001), or to use forwarders instead of skidders (Landford and Stokes, 1995). Given the extensive use of skidders in Romania, there are many cases in which skidding requires bladed roads, a solution which is recommended when the terrain slope is less than 40%, a case in which the roads should be designed with longitudinal slopes of 5 to 15%, exceptionally 20-25% (Oprea, 2008). On slopes less than 20-25%, the best approach is to develop skid trails oriented on the slope (Oprea, 2008) a solution that is considered not to trigger major erosion processes up to slopes of 20-30% (Ciortuz, 1981). Nevertheless, practice has showed that skidders can operate on much higher slopes, obviously with consequences in terms of skid trails rutting. Once formed, the ruts are the subject of the particle transportation by various mechanisms. Initially, the rut formation in terms of depth, is influenced by the soil moisture and the number of machine passes (see for instance: Greacen and Sands, 1980; Eliasson and Wasterlund, 2007; McNabb et al., 2001; Rollerson, 1990; Turcotte et al., 1991). Then, the ruts are growing in depth especially under the influence of the water-flux particle transportation (Beschta, 1978; Grayson et al., 1993; Kreutzweiser and Capell, 2001; Wallbrink et al., 2002).

Monitoring the erosion associated with timber harvesting operations (Rice, 1999), and especially that associated with timber skidding, requires the existence of data to be compared for different time moments, since different practices used to design skidding roads and trails may affect the extent of the erosion process. The latter is also depending on the soil types and their physical properties.

Until now, a lot of effort has been committed to find new methods and tools able to evaluate the soil impact in harvesting operations, including here the erosion rates associated with timber harvesting practices. Nevertheless, few studies addressed how the skidding infrastructure practices and design in terms of geometry, affects the extent of erosion processes.

This study was implemented to test if the practices associated with the skidding network development (longitudinal slope of the skid trails), as well as the soil type could be significant factors affecting the erosion extent on skid trails. Therefore, the objectives of this study were to (1) evaluate the erosion state of the skidding trails as a function of their longitudinal slope, by quantifying the affected area of cross-section placed on the skid trails and developing empirical models to characterize such a relation and (2) to empirically evaluate if the erosion extent is affected by the type of soil on which the skid trail was developed.

2. Materials and method

This study was carried out in the Forest Management Unit no. 3 Piatra Mare, located in the proximity of Brașov, Romania (Fig. 1), based on field data that was collected in May-June of 2012. Forest (vegetation) characteristics are important factors which affect the erosion rates for given territories. A description of the vegetation from the studied area is given in Table 1. A great variability of parent materials characterizing the bedrock was identified in the studied zone as described by the forest management plan of the studied area. Generally, they are composed of hard rocks, which influenced the formation and evolution of the forest soils, with predominance of conglomerates, limestone, freestone, freestone-limestone flysch, green clays and gravels. The conglomerates incorporate in their masses white and grey limestone, quartz, marl, freestone, mica-schist, as well as chalky cement, salt and sand. The slopes are formed on clastic deposits, which are frequently covered by deluvial materials. Typical for moderate slopes are the loam covertures while the meadows are located on gravel and sand.

In such conditions, a great soil variety is characteristic to the studied area. By considering only those forest compartments in which the skidding network was identified and studied, the following soil types were characteristic (Fig. 5): type 1 (1703) - Litic Rendzina, type 2 (3101) - Typical Eutric Cambisoil, type 3 (3305) - Litic Dystric Cambisoil, type 4 (4101) - Leptic Podzol, type 5 (3302) - Umbric Dystric Cambisoil and type 6 (3301) - Typical Distric Cambisoil. The first soil type (Litic Rendzina) is generally characterized by a medium-fine texture resulted from limestone alteration and clay accumulation (Târziu, 1997; Târziu et al., 2002). Usually, it presents fragments from the parental material starting from the surface. The second soil type (Typical Eutric Cambisoil) has an undifferentiated, medium to fine texture along its profile, with a polyhedral structure in the cambic horizon (Târziu, 1997; Târziu et al., 2002).

The third, fifth and sixth soil types (Litic Dystric Cambisoil, Umbric Dystric Cambisoil and Typical Distric Cambisoil), share a fine-medium texture, undifferentiated along the profile, and a poor polyhedral structure, developed in the cambic horizon (Târziu, 1997; Târziu et al., 2002). In addition, the third soil type (Litic Dystric Cambisoil) is characterized by a rocky layer closer to the surface (Târziu, 1997; Târziu et al., 2002).

The fourth soil type (Leptic Podzol) has a sandy-loamy texture, undifferentiated along the profile. It also shows a poor structure and, in some cases, it has no structure at all (Târziu, 1997; Târziu et al., 2002). To carry on the study, a map of the forest management unit was used to plan the field activities. Then, field surveys were conducted to identify the skidding trails and to collect the data on erosion. To this end, each forest road was travelled by foot and in each case in which a skidding trail was found to join the forest road, the corresponding joint was positioned using a handheld GPS receiver (Garmin 60 CSx unit). The next step was that of mapping all the skid trails starting from each joint with the forest road up to the end of the skid trail. In such cases in which skid trail ramifications were found in the field, their locations were positioned using the same device, following their mapping using the same algorithm.

Following these steps, in the studied area was identified a skidding network having a total length of 7845.47 m. To estimate the state of skidding trails in terms of erosion, in the field, each skid trail was divided in homogeneous segments based on its longitudinal (design) slope (slope variation along the skid trail segment less than ±2%). To this end, an inclinometer and a graded rod were used to collect the slope data.

To effectively evaluate the erosion, the average scoured cross-section area of each skid trail segment was determined by considering a minimum three measured cross-sections on each segment. When a homogeneous skid trail segment showed a constant slope on a long distance, cross-sections were placed at maximum 50 m far from each other. The concept used in the field sampling activity is shown in Fig. 2.

Table 1. The main characteristics of the forest stands from the Management Unit no. III Piatra Mare

Specifications	***Species***										***Tota l***
	Spruce	***Beech***	***Fir***	***Scots Pine***	***Maple***	***European Black Pine***	***Larch***	***Other resinous species***	***Other broadleaved hardwood species***	***Other broadleaved softwood species***	
Composition [%]	43	31	21	2	2	-	-	-	1	-	100
Production class	3.0	3.1	2.8	2.4	3.1	2.7	2.8	2.3	3.1	3.1	3.0
Density	0.71	0.75	0.74	0.60	0.84	0.53	0.70	0.77	0.79	0.86	0.73
Average age [years]	88	96	97	109	75	107	91	103	86	22	93

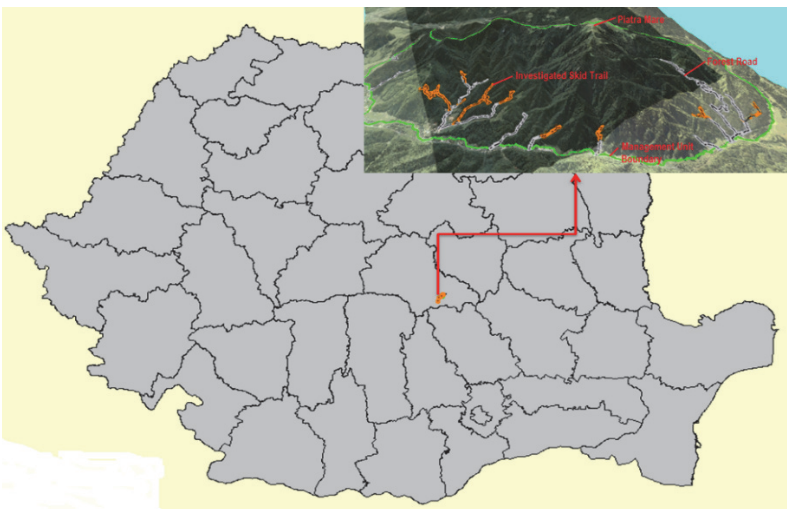
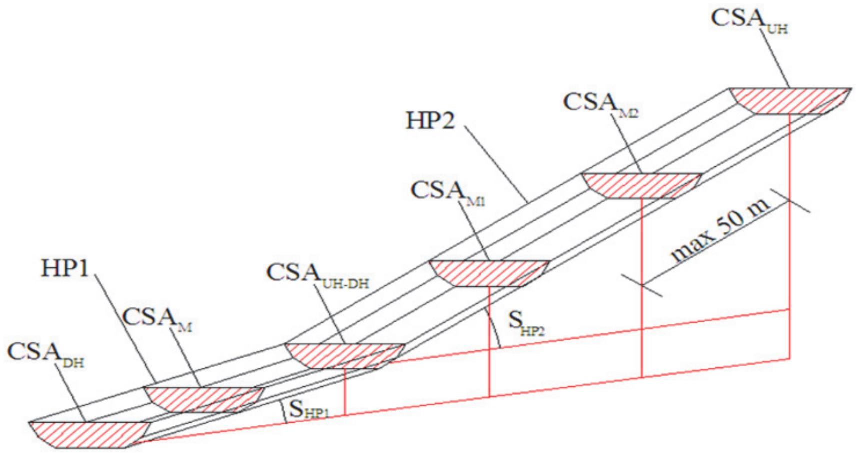


Fig. 1. Map of study location showing transportation and skidding networks



LEGEND:
HP1-HP2 – homogeneous skid trail segments
CSADH – area of cross-section in the downhill part of skid trail segment
CSAM – area of cross-section in the middle part of the skid trail segment
CSAUH-DH – area of cross-sections common to two consecutive skid trail segments
CSAM1, CSAM2 – area of cross-sections placed based on the 50 condition
CSAUH – area of cross-section in the uphill part of skid trail segment
SHP1, SHP2– slopes of the skid trail segments 1 and 2

Fig. 2. Field sampling criteria – placing the cross-sections

Each cross-section was coded to allow the identification of its position in the homogeneous skid trail segment and a GPS location was collected as well. To get the data needed to evaluate the cross-section area, image files were taken on a perpendicular direction at each location, after some preparation which consisted of placing the rod in a centered-vertical position near a specially-manufactured rope equipped with fixation nails (Fig. 3). After taking the pictures, each of them was saved on camera's memory, using the same file name as that of the positions taken by the GPS unit.

Fig. 3. Using the rope equipped with fixation nails to delineate a cross-section

At the office, both, the image and the point files were downloaded into a computer. The calculation of the eroded cross-section areas involved several steps. First, the image files were imported into the AutoCAD environment, where they were scaled by overlapping the rod taken into images on an equivalent rod drawn at real scale in AutoCAD.

Then, by constructing closed polylines over the rope representation from the downloaded image files (Fig. 4), the areas of the scoured cross-sections were obtained. The resulting areas were organized in a spreadsheet on the following categories: homogeneous skid trail segments, skid trails, and skid trail network.

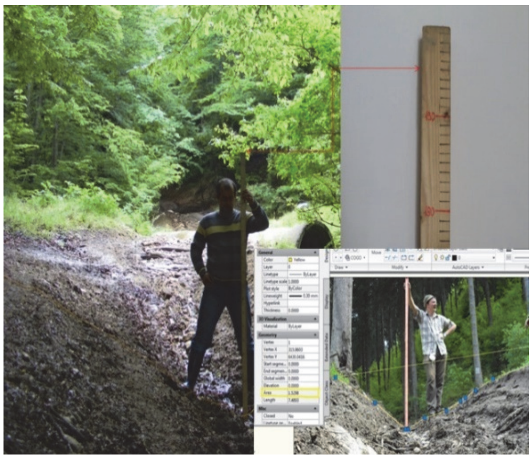


Fig. 4. Digitization of the cross-section areas using AutoCAD

Sloped lengths of the skid trails were computed using the slope and length data collected in the field. Additional data on the skidding trails development was extracted by the geographical analysis using the AutoCAD environment. The soil types were collected from the management plan of the studied forest management unit, by taking in consideration those forest compartments in which skidding trails were identified and studied. Additional observations were made during the field study in order to correct the data provided by the forest management plan.

Using the field collected and office processed data, the main geometrical characteristics of the skidding network as well as their corresponding eroded areas were determined. Also, empirical dependence relations were taken into study to check if the erosion of the skid trails depends on their geometry. To this end, the least-square simple linear regression technique was used to build an empirical model having as a predicted variable the area of the cross-section and as a predictor variable the slope of the skid trail segments.

3. Results and discussion

Data analysis showed that most of the skid trails (5178 m) were developed near the main streams. Also, the mean longitudinal slope of the skid trails was of 16.16% (Table 2), and more than a quarter of the analyzed skid trails were developed with longitudinal slopes of 15 to 20% (Table 3). In addition, about 12% of the skid trails had a slope greater than 25%.

Due to the possible influence of multiple factors, a great variation was found when trying to explain the erosion-affected cross-section area as a function of longitudinal slope of the skid trails. In order to manage this variation, slope categories were designed and the mean values of the cross-section areas were calculated for each category. The categories of longitudinal slopes as well as their centers and average values of the cross-section areas are shown in Table 4. For the studied conditions, the estimation of the cross-section areas as a function of the longitudinal slope is given in Eq. (1) while the model's statistics are given in Table 5. As shown, strong dependence relations were found between the skidding network development practices in terms of longitudinal slope and the associated erosion processes. As a rule, the higher the slopes the greater the erosion process. Even in conditions of no or reduced slope, erosion was found to be significant, but it was smaller compared to that characterizing the sloped terrains. For instance, those skid trails developed with a slope greater than 30%, were characterized by an addition of more than 20% to the cross-section area compared with those having a slope of 20-25%.

$$CSA=0.542+0.0112Lds \qquad (1)$$

where: CSA - Area of mean cross-section per slope category [m^2]; Lds - skid trail longitudinal slope [%].

According to other studies that explained the way that regression results should be interpreted (Olsen et al., 1998), the free term of the model shown in Eq. 1 can be seen as that part of the variation not explained by the longitudinal slope, therefore the erosion can be present also due to the contribution of other factors than the longitudinal slope itself. Obviously, one of the additional factors is the soil type itself (Fig. 5), because the average cross-section areas as a function of the soil type clearly indicate a trend attributing smaller values to those soil types characterized by the presence of the rock bed near the surface. Clearly, in such cases, the erosion acts until the water reaches the rock bed and slows down after that. For the rest of the analyzed soil types, the erosion extent was dependent, besides the slope, on the physical properties of the soils.

Table 2. Main characteristics of the studied skidding network

Parameters of skid trail network geometry	***Values***			
	Minimum	***Maximum***	***Average***	***Total***
Total length of the skidding trails [m]	-	-	-	7842.41
Longitudinal slope [%]	1.00	38.50	16.16	-
Development procedure - near streams [%]	-	-	-	66
Development procedure - on slope, ascending [%]	-	-	-	34
Density [m/ha]	-	-	5.67	-
Number of major curves [angle <90°]	-	-	-	13

Table 3. Length and share of the skid trails on slope categories

Category of longitudinal slope	***Length and share of the skidding trails***	
	Length [m]	***Share [%]***
<5%	326.31	4.16
5-10%	1752.97	22.34
10-15%	1434.65	18.29
15-20%	2076.77	26.47
20-25%	1268.45	16.17
25-30%	363.99	4.64
30-35%	385.58	4.91
>35%	236.75	3.02

Table 4. Mean cross-section area as a function of slope category

Category of longitudinal slope	*Center of category [%]*	*Mean area of the cross-sections [m^2]*
<5%	2.50	0.61
5-10%	7.50	0.70
10-15%	12.50	0.59
15-20%	17.50	0.68
20-25%	22.50	0.81
25-30%	27.50	0.82
>30%	35.00	0.99

Table 5. Regression statistics for Eq. (1)

Regression Statistics	
Coefficient of correlation (R)	0.904811
Coefficient of determination (R2)	0.818683
Adjusted coefficient of determination (Adj. R2)	0.782419
Standard error	0.065845
P-value	
Intercept	0.000104
Lds	0.005098

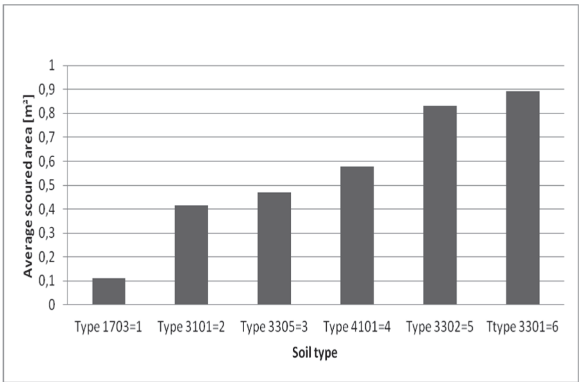


Fig. 5. Distribution of average scoured area on studied soil types: 1 - Rendzina having a rocky horizon starting after first 20 cm, 2 - Typical Eutric Cambisoil, 3 - Dystric Cambisoil having a rocky horizon starting after first 30 cm, 4 - Leptic Podzol, 5 - Umbric Dystric Cambisoil, 6 - Typical Distric Cambisoil

Volume of soil-loss due to erosion processes was calculated based on the mean areas of cross-sections and the corresponding lengths of the skid trails. It was found that compared to the original configuration of the soil, a total volume of 5976.50 m3 was lost (as of June 2012), resulting in an average quantity of soil loss of 0.76 m3 per meter of skid trail network. This corresponds to an average calculated width of the skid trails of 2.2 m. Compared to other studies (Rice, 1999), the quantity of soil loss (due to different mechanisms) seems to be greater and it may be the consequence of poorer practices in timber skidding operations.

However, for quite similar conditions, other studies reported greater erosion rates associated with logging infrastructure (Best et al., 1995; Weaver et al., 1995). Greater erosion rates were those specific to clear cuts, when the logging roads were not properly maintained (Weaver et al., 1995). However, this is not the case of the Romanian forestry where the continuous cover silvicultural systems are predominant.

According to this study, in those cases where skid trails had no or reduced slope, the average areas of the cross-sections were almost half the size of those found in high slope conditions (0.61 m2 for <5% slope versus 0.99 m2 for >30% slope). Higher cross-section areas were characteristic to longitudinal slopes greater than 20%. However, some particular cases may occur in reality due to several local factors such as the soil type, skid trail position and geometry (in curves, the affected areas were greater). While many factors may affect the erosion processes (Best et al., 1995; Rice, 1999; Weaver et al., 1995), in this study, the erosion extent in terms of cross-section areas was explained to a great proportion (R2 = 0.82) by the longitudinal slope of the skid trails.

Due to their physical properties, different soil types are characterized by different conditions for the rut formation, scouring and erosion processes. In addition, the location of a given skid trail relative to the forest road, therefore, the water amount which is undertaken by it, may further affect the erosion process and its extent judged by the area of a cross-section. However, such factors were not taken into account in this study. The extent of the eroded cross-section areas as a function of the soil type can be attributed also to the soil physical properties such as the edaphic volume.

4. Conclusions

The erosion process is the result of the multiple action factors and it can be accelerated by the human activity. Timber harvesting practices may have their own influence on the erosion extent, by creating premises for erosion acceleration, but not all the timber skidding development practices influence the forest soils erosion in the same way, as demonstrated by the current study. Therefore, by reducing the slope of the skid trails, the extent of erosion processes can be partially controlled.

References

Apăfăian A.I., Proto, A.R., Borz S.A., (2017), Performance of a mid-sized harvester-forwarder system in integrated harvesting of sawmill, pulpwood and firewood, *Annals of Forest Research*, **60**, 227-241.

Anderson H.W., (1954), Suspended sediment discharge as related to streamflow, topography, soil and land use, *Transactions - American Geophysical Union*, **35**, 268-281.

Beschta R.L., (1978), Long-term patterns of sediment production following road construction and logging in the Oregon Coast Range, *Water Resources Research*, **14**, 1011-1016.

Best D.W., Kelsey H.M., Hagans D.K., Alpert M., (1995), *Role of Fluvial Hillslope Erosion and Road Construction in the Sediment Budget of Garrett Creek, Humboldt County, California*, In: *Geomorphic Processes and Aquatic Habitat in the Redwood Creek Basin, Northwestern California*, Nolan K.M., Kelsey H.M., Marron D.C. (Eds.), U.S. Geol. Survey Prof. Pap. 1454, M1-M9.

Borz S.A., Ignea G., Popa B., Spârchez G., Iordache E., (2015), Estimating time consumption and productivity of roundwood skidding in group shelterwood system - a case study in a broadleaved mixed stand located in reduced accessibility conditions, *Croatian Journal of Forest Engineering*, **36**, 137-146.

Borz S.A., Bîrda M., Ignea G., Popa B., Câmpu V.R., Iordache E., Derczeni R.A., (2014a), Efficiency of a Woody 60 processor attached to a Mounty 4100 tower yarder when processing coniferous timber from thinning operations, *Annals of Forest Research*, **57**, 333-345.

Borz S.A., Ignea G., Popa B., (2014b), Modelling and comparing timber winching performance in windthrow and uniform selective cuttings for two Romanian skidders, *Jurnal of Forest Research*, **19**, 473-482.

Borz S.A., Ignea G., Vasilescu M.M., (2014c), Small gains in wood recovery rate whan disobeying the recommended motor-manual tree felling procedures: another reason to use the proper technical descriptions, *Bioresources*, **9**, 6938-6949.

Borz S.A., Ciobanu V., (2013), Efficiency of motor-manual felling and horse logging in small-scale firewood production. *African Journal of Agricultural Research*, **8**, 3126-3135.

Borz S.A., Dinulică F., Bîrda M., Ignea Gh., Ciobanu D.V., Popa B., (2013) Time consumption and productivity of skidding silver fir (*Abies alba* Mill.) round wood in reduced accessibility conditions: a case study in windthrow salvage logging from Romanian Carpathians, *Annals of Forest Research*, **56**, 363-375.

Christopher E.A., Visser R., (2007), Methodology for evaluating post-harvest erosion risk for the protection of water quality, *New Zealand Journal of Forestry*, **52**, 20-25.

Ciortuz I., (1981), *Forest Soil Conservation* (in Romanian), Didactic and Pedagogic Press, Bucharest, Romania.

Dyrness C.T., (1967), Mass soil movements in the H.J. Andrews experimental forest, USDA Forest Serv. Res. Paper PNW-42. Pacific Northwest Forest and Range Exp. Sta., Portland, Oregon, On line at: https://www.biodiversitylibrary.org/bibliography/87886#/summary.

European Commission, (2014), A new strategy for forests and forestry sector, On line at: http://publications.europa.eu/resource/cellar/21b27c38-21fb-11e3-8d1c-01aa75ed71a1.0022.04/DOC_1, Accessed: 07.03.2018.

Eliasson L., Wasterlund I., (2007), Effects of slash reinforcement of strip roads on rutting and soil compaction on a moist fine-grained soil, *Forest Ecology and Management*, **252**, 118-123.

Furbish D.J., (1981), *Debris Slides Related to Logging of Streamside Hillslopes in Northwestern California*, M.Sc. Thesis, Humboldt State University.

Gligoraş D., Borz S.A., (2015), Factors affecting the effective time consumption, wood recovery and feeding speed when manufacturing lumber using a FBO-02 cut mobile bandsaw, *Wood Research*, **60**, 329-338.

Grayson R.B., Haydon S.R., Jayasuriya M.D.A., Finlayson B.L., (1993), Water quality in mountain ash forests - separating the impacts of roads from those of the logging operations, *Journal of Hydrology*, **150**, 459-480.

Greacen E.L., Sands R., (1980), Compaction of forest soil-a review, *Australian Journal of Soil Research*, **18**, 163-189.

Hartanto H., Ravi P., Widayat A.S.E., Asdak C., (2003), Factors affecting runoff and soil erosion: Plot-level soil loss monitoring for assessing sustainability of forest management, *Forest Ecology and Management*, **180**, 361-374.

Heinimann H.R., (2012), Life cycle assessment (LCA) in forestry - state and perspectives, *Croatian Journal of Forest Engineering*, **33**, 357-372.

Heinimann H.R., (2007), Forest operations engineering and management - the ways behind and ahead a of a scientific discipline, *Croatian Journal of Forest Engineering*, **28**, 107-121.

Ignea G., Ghaffaryian M.R., Borz S.A., (2017), Impact of operational factors on fossil energy inputs in motor-manual tree felling and processing: results of two case studies. *Annals of Forest Research*, **60**,161-172.

Kreutzweiser D.P., Capell S.S., (2001), Fine sediment deposition in streams after selective forest harvesting without riparian buffers, *Canadian Journal of Forest Research*, **31**, 2134-2142.

Landford B.L., Stokes B.J., (1995), Comparison of two thinning systems. Part 1. Stand and Site Impacts, *Forest Products Journal*, **45**, 74-79.

Laffan M., Jordan G., Duhig N., (2001), Records impacts on soil from cable-logging steep slopes in Northeastern Tasmania, Australia, *Forest Ecology and Management*, **144**, 91-99.

McNabb D.H., Startsev A.D., Nguyen H., (2001), Soil wetness and traffic level effects on bulk density and air-filled porosity of compacted boreal forest soils, *Soil Science Society of America Journal*, **65**, 1238-1247.

Moskalik T., Borz S.A., Dvořák J., Ferencik M., Glushkov S., Muiste P., Lazdiņš A., Styranivsky, O., (2017), Timber harvesting methods in Eastern European countries: A review, *Croatian Journal of Forest Engineering*, **38**, 231-241.

Munteanu C., Ignea G., Akay A.E., Borz S.A., (2017), Yarding pre-bunched stems in thinning operations: estimates on time consumption, *Bulletin of the Transilvania University of Braşov*, **10**, 43-54.

Nolan K.M., Kelsey H.M., Marron D.C., (1995), *Geomorphic Processes and Aquatic Habitat in the Redwood Creek Basin*, Northwestern California, U.S. Geological Survey Prof. Paper 1454. U. S. Govt. Printing Office, Washington, D.C.

Olsen E.D., Hossain M.M., Miller M.E., (1998), *Statistical comparison of methods used in harvesting work studies*. Oregon State University, Forest Research Laboratory, Corvallis, OR, Research contribution No. 23, On line at: https://ir.library.oregonstate.edu/concern/technical_reports/fn107021t.

Oprea I., (2008), *Timber Harvesting Technology*, Transilvania University Press, Braşov, Romania.

Rauch P., Wolfsmayr U.J., Borz S.A., Triplat M., Krajnc, N., Kolck M., Oberwimmer R., Ketikidis C., Vasiljevic A., Stauder M., Mühlbergg C., Derczeni R., Oravech M., Krissakovah I., Handlos M., (2015), SWOT analysis and strategy development for forest fuel supply chains in South East Europe, *Forest Policy and Economics*, **61**, 87-94.

Rice R.M., (1999), Erosion on logging roads in Redwood Creek, Northwestern California, *Journal of the American Water Resources Association*, **35**, 1171-1182.

Târziu D., Spârchez G., Dincă L., (2002), *Soils of Romania*, For Life Press, Braşov, Romania.

Târziu D., (1997), *Pedology and Forest Sites*, Ceres Publishing House, Bucharest, Romania.

Turcotte D.E., Smith C.T., Federer C.A., (1991), Soil disturbance following whole-tree harvesting in North-Central Maine, *Northern Journal of Applied Forestry*, **8**, 68-72.

Wallbrink P.J., Roddy B.P., Olley J.M., (2002), A tracer budget quantifying soil redistribution on hillslopes after forest harvesting, *Catena*, **47**, 179-201.

Weaver W.E., Hagans D.K., Popenoe J.H., (1995). *Magnitude and Causes of Gully Erosion in the Lower Redwood Creek Basin, Northwestern California*. In: *Geomorphic Processes and Aquatic Habitat in the Redwood Creek Basin, Northwestern California*, Nolan K.M., Kelsey H.M., Marron D. C. (Eds), U.S. Geol. Survey Prof. Pap. 1454, 11-121.